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Effect of Plant Growth-Promoting Rhizobacteria (PGPR) Concentrations on the growth of Agarwood (*Aquilaria malaccensis*) Seedlings in Ex-Coal Mine Soil

Benni satria[1*], Armansyah[1], Efderilla[1], Daimon Syukri[2] and Hendra Saputra[3]

[1]Department of Agronomy, Faculty of Agricultural, Andalas University, Padang, Indonesia; [2]Department of Food and Agricultural Products, Faculty of Agricultural Technology, Andalas University, Padang, Indonesia; [3]Department of Agro-industrial Technology, Faculty of Agricultural Technology, Andalas University, Padang, Indonesia.
[*]Corresponding author's e-mail: bennisatriaunand@gmail.com

Agarwood-producing plants (*Aquilaria malaccensis* Lamk.) have high economic value, but excessive exploitation without reforestation causes scarcity. This study aims to determine the interaction of Plant Growth-Promoting Rhizobacteria (PGPR) concentrations to increase the growth of agarwood-producing plant seedling genotypes in former coal mining areas. This study used an experimental method in a Factorial Randomized Block Design (RBD) with two factors: agarwood seedling genotypes and PGPR concentrations. The two genotypes tested were *Aquilaria malaccensis* Lamk. and *Aquilaria microcarpa* Lamk. The four PGPR concentrations applied were 0, 10, 20, and 30 ml/L. Growth data were analyzed using the F-test at the 5% level and then followed by Duncan's New Multiple Range Test (DNMRT) if an interaction was found. PGPR applications showed a significant effect on seedling growth. A strong interaction was found between PGPR concentration and genotype. The PGPR concentration of 20 ml/L was the most effective, significantly increasing the height, number and size of leaves, and root weight of the *Aquilaria malaccensis* genotype. Interestingly, both genotypes showed a 100% survival rate and were ready for replanting (reforestation) on post-mining land. The addition of PGPR, especially at a concentration of 20 ml/L, can significantly increase the growth of agarwood seedlings, making it an effective biological agent for cultivation on marginal land. The high survival rate indicates that these seedlings are adaptive and can be a solution for rehabilitating post-mining land and meeting market demand for agarwood.

Keywords: Agarwood plant, reforestation, coal mine soils, marginal lands, beneficial microbes,phytohormones, productivity.

INTRODUCTION

Indonesia's forests produce numerous products, both wood and non-wood. One such non-wood forest product is agarwood. Agarwood (*Aquilaria malaccensis* Lamk.) is a highly sought-after Non-Timber Forest Product (NTFP) commodity due to its resin content, which can be used as a base ingredient in perfumes, soaps, medicines, and cosmetics, making it a highly valuable commercial commodity. Agarwood plants have a high market value, encouraging people to utilize them. This has led to high exploitation of natural forests and increased logging of agarwood trees without reforestation (Satria et al., 2025). The investigation of plant growth-promoting rhizobacteria (PGPR) on Agarwood-producing plant seedlings (*Aquilaria malaccensis* Lamk.) in former coal mine planting media is crucial for understanding the implications of microbial inoculation in restoring degraded soils and enhancing the growth performance of economically significant species. PGPR are beneficial microbes that promote plant growth by producing phytohormones (auxins, gibberellins, cytokinins), enhancing nutrient uptake, and improving root development. They are vital for restoring degraded soils, including post-mining sites (Satria et al., 2025; Saputra et al., 2025). For instance, the inoculation of *Aquilaria malaccensis* with PGPR can not only boost growth metrics but also improve the soil's physical and chemical characteristics that are often compromised post-mining. Agarwood cultivation can be carried out both in forest areas and outside them (on agricultural land). The availability of agricultural land is decreasing due to land conversion, resulting in many marginal lands becoming less productive for agriculture. One example is former coal mining

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areas. Post-coal mine soils are highly dense and infertile, resulting in structural damage and nutrient degradation, making it difficult for plants to grow. The reduced biodiversity in post-coal mine soils results in less efficient decomposition processes. Furthermore, the low organic matter content hinders the improvement of the soil's physical, chemical, and biological properties. This impacts nutrient availability for plants and reduces the soil's capacity for plant growth. Post-coal mine soils are relatively low in the macronutrients N, P, K, and Mg (Kesumaningwati et al., 2018; Subhan, 2019).

The primary genetic material in coal is CHO, a combustible sedimentary rock. However, mining is a two-way street: one that stimulates the national economy and the other that can potentially damage the environment. Revegetating post-coal mined land through open-pit mining faces several challenges, similar to those encountered in coal mines. Common problems include high soil density, high acidity, low nutrient availability, high soil density, and high metal accumulation. The soil and pH in mining areas are also very low due to acid mine drainage. The results of the soil analysis conducted using X-ray Fluorescence Spectroscopy demonstrated the presence of various elements in the soil of former stone mines, including notable concentrations of AI (2.81%), Si (11.79%), S (0.16%), K (0.99%), Ca (0.73%), Ti (0.31%), Mn (0.08%), Fe (4.57%), Ba (0.11%),

and Ta (0.11%). Among these elements, silicon (Si) emerged as the most abundant element in the soil, a common occurrence in soil compositions. In addition, sulfur (S) was identified in the soil of former stone mines, where it is believed to induce stress in agarwood plants, releasing resin with a fragrant aroma. The presence of sulfur in the soil underscores its potential impact on plant physiology and resin production in stressed environments, as reported by (Aarabi et al., 2020); Narayan et al., 2023; Herman et al., 2024). The constituents present in soil derived from former coal mining sites that have been planted with agarwood trees are AI_2O_3 (5.3%), SiO_2 (25.22%), K_2O (1.19%), CaO (1.02%), TiO_2 (0.52%), Mn_2O_3 (6.54%), Sb_2O_3 (0.23%), BaO (0.12%), and Ta_2O_5 (0.14%). The analysis revealed that the concentration of silicon dioxide is the highest at 25%, followed by manganese, which suggests that these two components are the most prominent and play avital role in inducing environmental stress on the agarwood tree, ultimately leading to the production of fragrant agarwood resin (Satria et al., 2025). The drastic decline in soil fertility due to coal mining is caused by the removal of topsoil and overburden. At high concentrations, heavy metals enter plants through root cells through diffusion. At high concentrations, enzyme activity is disrupted by heavy metals due to modifications in protein structure or replacement of essential elements, resulting in deficiency symptoms. Plant Growth Promoting Rhizobacteria are a group of bacteria that can colonize the 1-2 cm area around plant roots (rhizosphere). This group of bacteria can have a positive impact on plant growth, including restoring soil fertility, acting as a nutrient provider (biofertilizer), and producing the growth hormone IAA (plant growth regulator) because they contain several microbes such as *Azotobacter, Bacillus, Pseudomonas, Rhizobacteria, and Rhizobium* (Jannah, 2022). PGPR containing Rhizobium can aid plant growth by forming symbiosis and colonizing roots, forming root nodules, thereby providing the nitrogen needed by plants (Jannah, 2022). Applying biofertilizer containing Bacillus sp. and Pseudomonas sp. to plants has the ability to act as antagonists, solubilize phosphate, produce phytohormones, and secrete enzymes such as chitinase, protease, and cellulose (Wulandari et al., 2019). Rhizome is a biofertilizer in a powder formulation containing bacteria capable of producing growth hormones, increasing plant resistance to pests and diseases, and increasing nutrient availability and absorption. Rhizome biofertilizer contains Rhizobium sp., *Bacillus polymixa*, and *Pseudomonas flourescens*. According to Rifka et al. (2019), administering PGPR Rhizome can increase plant nodulation and rooting, thus impacting the productivity of cultivated plants. The results of Kurniawan's (2018) also found that a PGPR concentration of 20 ml/liter had the best effect on the height, diameter, and length of Sengon (*Paraserianthes falcataria* L.) seedlings' roots. Based on the above background, a study was conducted entitled "The Effect of Several Concentrations of Plant Growth Promoting Rhizobacteria (PGPR) on the Growth of Agarwood-Producing Plant Seedlings (*Aquilaria malaccensis* Lamk.) in Former Coal Mine Planting Media". Based on the problems presented, the research questions for this experiment are: 1). How does PGPR concentration affect the growth of agarwood-producing plant seedlings in ex-coal mine planting media? 2). What is the best concentration for the growth of agarwood-producing plant seedlings after PGPR is applied to ex-coal mine planting media? The objectives of this experiment are: 1). To determine the effect of PGPR concentration on the growth of agarwood-producing plant seedlings in ex-coal mine planting media. 2). To determine the best PGPR concentration for the growth of agarwood-producing plant seedlings in ex-coal mine planting media. This research is expected to provide information on the use of PGPR to enhance the growth of agarwood-producing plant seedlings when cultivated in ex-coal mine planting media.

MATERIALS AND METHODS

This research was conducted in Salido, IV Jurai District, Pesisir Selatan Regency, West Sumatra. The study was conducted from June to December 2024. Soil analysis was conducted at the Star Laboratory Testing Laboratory, PT. Wiwiadi Bintang Sains.

This experiment used a factorial Randomized Block Design (RBD). The first factor was the genotype of agarwood-producing plant seeds, consisting of two levels: genotype (A):

Aquilaria malaccensis Lamk (A1) and *Aquilaria microcarpa* Lamk (A2). The second factor was the PGPR concentration, consisting of four treatment levels: PGPR concentration (K): 0 ml/L (K0), 10 ml/L (K1), 20 ml/L (K2), and 30 ml/L (K3). The observational data were analyzed using the F-test at a 5% significance level. If the calculated F is greater than the F table, then it is continued with the Duncan's New Multiple Range Test (DNMRT) at a 5% significance level. Observation variables include seedling height increase, seedling height increase, leaf number increase, longest leaf length, widest leaf width, seedling diameter, root weight and percentage of seedlings ready for distribution. Soil analysis was conducted to determine soil pH and the nutrient levels of Nitrogen (N), Phosphorus (P), Potassium (K), and Al-dd in the soil. Analysis was conducted using various methods depending on the soil type: pH using the electrometric method, Nitrogen (N) using the volumetric method, Phosphorus (P) using the Kjeldhal method, Potassium (K) using the Bray 1 method, and Al-dd using the 25% HCl extraction method. Soil samples were randomly collected at five locations in the former coal mine by hoeing to a depth of 0-20 cm and then placed in plastic bags. The soil samples were then analyzed at the Star Laboratory Testing Laboratory, PT. Wiwiadi Bintang Sains. The agarwood-producing plant seeds used in this study were obtained from an agarwood seed supplier in Lubuk Minturun, Koto Tangah District, Padang City, West Sumatra. A description of the agarwood plants is provided in Appendix 5. The criteria for the seeds used were approximately 4 months old, healthy visual appearance, and a height of 30-50 cm.

The planting medium used for agarwood cultivation is ex-coal mining soil from Salido, IV Jurai District, Pesisir Selatan Regency. The planting medium was prepared by mixing ex-coal mining soil with cow manure evenly in a 1:1 ratio in polybags. Each polybag was then labeled using a stapler. Based on soil analysis, the soil pH for the experiment was 4.23, which means liming is necessary to neutralize the pH. 8.85 g of dolomite is required per polybag.

Planting was carried out one week after dolomite application. Seedlings were transferred from small polybags to experimental polybags by tearing them open and carefully removing the seedlings. One agarwood seedling per polybag was planted in the planting hole and then covered with soil. The Plant Growth Promoting Rhizobacteria treatment was administered in liquid form at concentrations of 0 ml/liter, 10 ml/liter, 20 ml/liter, and 30 ml/liter. Fertilizer application was carried out five times at 0, 3, 6, 9, and 12 weeks after planting by watering around the seedling roots. PGPR was applied according to the concentration treatment in 1 liter of water. The recommended dosage of NPK (16:16:16) compound fertilizer for agarwood is 12 grams per seedling (Putra et al., 2023). Fertilization of agarwood plants was carried out once at 4 weeks after planting (WAP) with a dose of half the recommended NPK (16:16:16) fertilizer, namely 6 grams per seedling. Fertilization was carried out in the morning by digging a 5-7 cm deep hole 7 cm from the base of the stem and then covering it with soil. Variable observation includes a. Percentage Live Seedlings; b. Increase in Plant Height; c. Increase in Number of Leaves; d. Widest Leaf Width; e. Leaf Length Longest; f. Stem Diameter; g. Root Weight; h. Percentage Seeds Agarwood Ready Channel.

RESULTS AND DISCUSSION

***Percentage seeds life*:** The percentage of viable seedlings is one of the key determinants of the success or failure of a seedling to grow successfully in the field. The adaptability of seedlings to environmental conditions will influence growth performance. The results of the analysis of variance for the percentage of viable seedlings of agarwood-producing plant genotypes following PGPR concentrations did not indicate any interaction. Similarly, the genotype and PGPR concentration factors showed no significant differences, as seen in Table 1.

Table 1. Percentage of viable seedlings of agarwood-producing plant genotypes following various PGPR concentrations at 15 weeks after planting.

Genotype	Concentration (ml/l)			
Agarwood (A)	0.00	10	20	30
A. macrocarpa	100.00	100.00	100.00	100.00
A. malaccensis	100.00	100.00	100.00	100.00

Description: The numbers in the same column and row are different: No real according to the F test level real 5%

The percentage of live seedlings of agarwood-producing plant genotypes treated with PGPR concentrations showed the same effect, with a survival rate of 100%. This indicates that the agarwood-producing plant genotypes are capable of growing and adapting to the ex-coal mine soil and the addition of PGPR concentrations. The high survival rate is thought to be influenced by maintenance, environmental conditions, good seedling condition, adequate watering to meet water requirements, and the absence of pests and diseases. Who stated that a 100% survival rate for a plant indicates that the growing environment provides sufficient resources such as water, food, nutrients, air, and is free from pests and diseases. The seedlings in this experiment were transferred by carrying the medium from the original plant to the treatment medium without uprooting, ensuring the plants were not stressed and were able to grow well. The high survival rate is determined by good seedling quality and seedling maintenance at the beginning of the treatment (Sari et al, 2021).

***Increase tall seeds*:** Based on the analysis of variance using the F test at a significant level of 5%, it shows that the increase in the height of the genotype of agarwood-producing plant seeds due to the administration of PGPR concentration has not shown any interaction, likewise the genotype factor but the single factor of PGPR concentration shows a significantly

different effect as seen in Table 2.

Table 2. Increase in height of the genotypes of agarwood-producing plant seeds in giving a number of concentration PGPR 15 years old.

Genotype	Concentration PGPR (ml/l)			
Agarwood (A)	**0.00**	**10**	**20**	**30**
A. macrocarpa	14.00 b	15.00 b	22.50 a	27.00 a
	A	A	A	A
A. malaccensis	15.50 b	19.50 b	30.50 a	31.00 a
	A	A	B	A
KK = 12,10 %				

Description: Numbers followed by the same capital letters in the same row are not significantly different according to the DMRT test at the 5% level.

The data in Table 2 shows that the administration of PGPR concentrations where the concentrations of 20 ml/L and 30 ml/L are different from the concentrations of 0 ml/L and 10 ml/L, on the increase in the height of the agarwood-producing plant seedling genotypes.

Figure 1. Increase in height of genotypes of agarwood-producing plant seeds A: *Aquilaria malacensis* B: *Aquilaria microcarpa.*

The increase in agarwood seedling height was attributed to higher PGPR concentrations, with *A. malaccensis* showing a stronger response than *A. microcarpa* (Figure 1). As seedlings age, nutrient needs rise, and PGPR supports vegetative growth by stimulating metabolism and producing phytohormones. The PGPR used, containing *Pseudomonas fluorescens* and *Bacillus polymyxa*, produces auxin which accelerates seedling growth. The availability of sufficient nitrogen elements for plants will stimulate higher plant growth, and nitrogen deficiency will disrupt plant growth. This is in line with the opinion of Putra (2024) who stated that plants that lack nitrogen will experience slow and stunted growth. One of the functions of PGPR is to play a role in providing nutrients through the process of nitrogen fixation (N), namely binding free nitrogen in the air into ammonia (NH_3) which will be converted into amino acids which then become ammonium compounds (NH_4^-) and nitrate (NO_3^-) which are available and can be absorbed by plants (Anjarwati & Aini, 2020). The results of this experiment are in line with research where the provision of PGPR 30 ml/polybag affected the height of oil palm seedlings. The nutrient N is useful for increasing plant height and stimulating budding in plants. Bacteria from the genera *Pseudomonas*, *Azotobacter*, *Bacillus*, and *Seratia* have been identified as PGPR (Plant Based Plant Growth Regulatory Organisms) producing phytohormones that can enhance plant growth and yield, particularly auxin, which plays a key role in increasing plant height, yields, and soil fertility (Jannah 2022). Application of PGPR concentration shows more optimal results compared to with without PGPR. Matter This Because PGPR capable tolerate a variety of condition and give ability for plant for endure in condition land Which not enough fertile. As for chart increase tall seeds Agarwood-producing plants in several PGPR concentration treatments can be seen in Figure 2

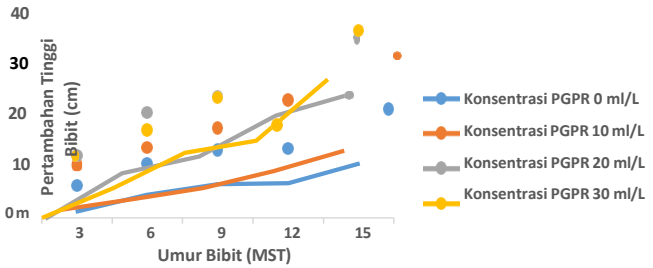

Figure 2. Graph of the increase in the height of agarwood-producing plant seedlings due to the administration of PGPR concentrations at the age of 3 MST to 15 MST.

Figure 2 illustrates that seedling height continued to increase until 15 weeks after planting, with significant differences observed among PGPR concentrations. Treatments of 20 and 30 ml/L consistently produced greater height growth compared to lower concentrations. This improvement is associated with the gradual increase in PGPR volume applied during each observation period, which supports nutrient absorption and maximizes seedling development. PGPR stimulates root system modifications through the production of indole-3-acetic acid (IAA), leading to enhanced lateral root branching and improved nutrient uptake, thereby accelerating overall plant growth (Pereira et al., 2020).

***Leaf number increase*:** Based on the analysis of variance using the F-test at a 5% significance level, the increase in the height of agarwood-producing seedling genotypes due to the application of PGPR concentrations indicates an interaction between genotype and PGPR concentration, indicating a significantly different effect (as seen in Table 3). The data in Table 3 show that the agarwood-producing seedling genotypes at various PGPR concentrations affected the increase in leaf number at 15 weeks after planting (WAP). This suggests that the PGPR concentrations used in this experiment optimally affected the number of leaves of the

agarwood-producing seedling genotypes. The *A. malaccensis* genotype at a concentration of 20 ml/L showed the best results in leaf increase compared to the other concentrations. This indicates that the seedlings treated with PGPR received adequate nutritional support compared to those without PGPR.

Table 3. Increase in the number of leaves of Agarwood-producing seedlings when given several concentrations of PGPR at the age of 15 weeks after planting.

Genotype	Concentration (ml/l)			
Agarwood (A)	**0.00**	**10**	**20**	**30**
A. macrocarpa	6,00 b	10,00 b	11,00 a	12,00 a
	A	A	B	A
A. malaccensis	8,00 b	12,00 b	19,00 a	16,00 a
	A	A	B	A
KK = 10,99 %				

Description: Numbers followed by the same capital letter in the same row and numbers followed by the same lower case letter in the same column are not significantly different according to the DMRT test at the 5% level.

Table 3 indicates that PGPR concentrations significantly influenced the number of leaves at 15 WAP, with the *A. malaccensis* genotype at 20 ml/L showing the best response. This result demonstrates that seedlings treated with PGPR received more adequate nutritional support compared to those without treatment. The positive effect is associated with microorganisms in PGPR, such as *Bacillus sp.*, which produce auxin, cytokinin, and IAA that stimulate cell division, regulate enlargement, and support root development. The role of nitrogen is also crucial in leaf formation, as sufficient N stimulates vegetative growth while deficiency can suppress leaf production (Nugraha et al., 2023). In addition, PGPR application improves nutrient availability through the activity of Rhizobium, Pseudomonas, and Bacillus, which are known to increase nitrogen and phosphorus absorption. These microbes also produce growth hormones that enhance physiological processes needed for leaf development. However, the influence of PGPR is not always visible on every growth parameter within a short period, as its effects are often more prominent in root and stem growth compared to leaf number. Nevertheless, the improvement in leaf production at optimal PGPR concentrations suggests a synergistic effect between nutrient supply and hormone production in supporting overall seedling performance. Leaf formation in plants is strongly influenced by genetic and environmental factors. Sunlight can influence leaf morphology, particularly leaf width. Light intensity will affect leaf width and the properties or characteristics of the resulting fibers. Light intensity influences cell enlargement and differentiation. Low light intensity also results in plants with larger, thinner leaves, larger stomata, thinner epidermal cell layers, a greater number of leaves, and more intercellular space (Zulkifli et al., 2022).

***Increase in length of longest leaf*:** Based on the analysis of variance using the F-test at the 5% significance level, the increase in the height of agarwood-producing seedling genotypes due to the application of PGPR concentrations indicates an interaction between genotype and PGPR concentration, indicating a significantly different effect, as seen in Table 4.

Table 4. Increase in the Length of the Longest Leaves of Agarwood-Producing Plant Seedlings when given several PGPR concentrations at 15 MST.

Genotype	Concentration (ml/l)			
Agarwood (A)	**0.00**	**10**	**20**	**30**
A. macrocarpa	2,12 b	2,17 b	4,10 a	5,90 a
	A	A	B	A
A. malaccensis	3,00 b	3,02 b	6,70 a	6,80 a
	A	A	B	A
KK = 7,30 %				

Description: Numbers followed by the same capital letter in the same row and numbers followed by the same lower case letter in the same column are not significantly different according to the DMRT test at the 5% level.

PGPR concentrations yield better results than those without PGPR. This is because the microorganisms contained in PGPR, including Bacillus sp., function to produce plant growth hormones such as auxin, cytokinin, and IAA to stimulate cell division, regulate cell enlargement, and stimulate root growth. Furthermore, the nitrogen in PGPR plays a crucial role in leaf formation (Nugraha et al., 2023). Although PGPR is known to enhance plant growth through hormone production and increased nutrient uptake, its effects are not always visible on all growth parameters, especially in the short term.

***Increase in widest leaf width*:** Based on the analysis of variance using the F-test at a 5% significance level, the increase in the height of agarwood-producing plant genotypes due to the application of PGPR concentration indicates an interaction between genotype and PGPR concentration, indicating a significantly different effect, as seen in Table 5. The data in Table 5 shows that the administration of several PGPR concentrations affected the increase in the widest leaf width of agarwood-producing seedlings aged 15 weeks after planting. This suggests that the PGPR concentration used in this experiment provided an optimal effect on the widest leaf width, but was better than without PGPR. It can be seen that the agarwood-producing seedling genotype at a concentration of 20 ml/L showed the best results compared to the other concentrations.

Table 5. Width Leaf Longest Agarwood-Producing Plant Seedlings on giving a number of concentrations PGPR age 15 MST.

Genotype	Concentration (ml/l)			
Agarwood (A)	0.00	10	20	30
A. macrocarpa	1,20 b	2,00 b	2,20 ab	3,60 a
	A	A	B	A
A. malaccensis	1,70 b	2,20 b	3,90 a	4,00 a
	A	A	B	A
KK = 6,04 %				

Description: Numbers followed by the same capital letter in the same row and numbers followed by the same lower case letter in the same column are not significantly different according to the DMRT test at the 5% level.

The average longest leaf width exceeded the description, and the leaf width also approached the maximum limit described. This indicates that seedlings treated with PGPR received adequate nutritional support compared to those without PGPR.

The administration of PGPR concentrations produced better results than those without PGPR. This is because the microorganisms contained in PGPR, one of which is Bacillus sp., function to produce plant growth hormones such as auxin, cytokinin, and IAA to stimulate cell division, regulate cell enlargement, and stimulate root growth. Furthermore, the nitrogen in PGPR plays a crucial role in leaf formation in plants (Nugraha et al., 2023). Although PGPR is known to enhance plant growth through hormone production and increased nutrient uptake, its effects are not always visible on all growth parameters, especially over a short period of time. The rate of leaf growth can be seen in Figure 3.

Leaf formation in plants is determined by both genetic and environmental factors, with sunlight playing a major role in shaping leaf morphology, particularly leaf width. Light intensity affects not only leaf size but also the anatomical and physiological properties of leaves, including fiber characteristics. Adequate sunlight promotes optimal cell enlargement and differentiation, leading to leaves that are thicker, more compact, and structurally stronger. Conversely, low light intensity tends to produce leaves that are larger but thinner, with wider stomata, thinner epidermal layers, and more intercellular spaces, which in turn increase leaf number but reduce structural strength (Zulkifli et al., 2022). These morphological adjustments represent adaptive strategies that enable plants to maximize light capture under shaded conditions, while also influencing photosynthetic efficiency and overall growth performance.

***Stem diameter*:** Based on the analysis of variance using the F test at a 5% significance level, the increase in the height of agarwood-producing plant genotypes due to the application of PGPR concentrations showed no interaction, indicating a non-significant difference in the effect. The same applies to both single factors, namely the genotype factor and the PGPR concentration factor, as can be seen in Table 6.

Table 6. Stem Diameter of Genotypes of Agarwood-producing Plant Seedlings when given several PGPR concentrations at 15 MST.

Genotype	Concentration PGPR (ml/l)				*Rata*
Agarwood (A)	0.00	10	20	30	*rata*
A. macrocarpa	0,37	0,43	0,44	0,45	0,44
A. malaccensis	0,43	0,44	0,50	0,49	0,47
Rata rata	0,43	0,44	0,47	0,47	
KK = 12,76 %					

Description: The numbers in the same column and row are not significantly different according to the F test at the 5% level.

Table 6 shows that the genotypes of agarwood-producing plants at various PGPR concentrations had the same effect on the stem diameter of agarwood-producing plant seedlings, with stem diameters ranging from 0.44 to 0.47 cm. The highest average was found at a PGPR concentration of 20 ml/L, at 4.70 cm. This is thought to be due to the relationship between leaf number and stem diameter. Results test This No in line with study Kurniawan (2018) which showed that a PGPR concentration of 20 ml/L significantly affected the diameter of Sengon seedlings. However, in this study, a PGPR concentration of 20 ml/L already produced the highest average compared to other treatments. The increase in stem diameter was influenced by the availability of P and K elements. The use of PGPR is suspected can influence growth plant in a way positive due to there is compound regulator growth that can stimulate development plant as well as increase stem diameter size through hormone resulting growth. IAA is one of them hormone growth plants which are group auxin and its role as driver growth plants (Istiqomah et al., 2017). PGPR has the ability to increase the availability of nutrients in the soil, including phosphorus (P) and potassium (K).

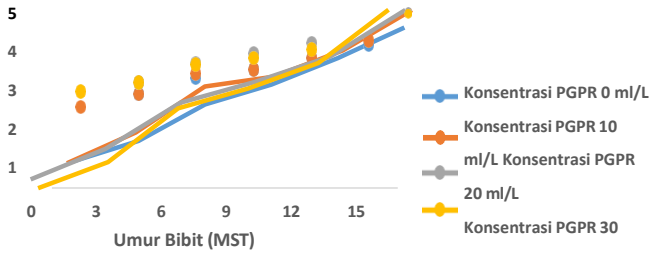

Figure 3. Chart stem diameter on giving a number of concentrations PGPR 15 years old.

Bacteria in PGPR, such as *Bacillus* and *Pseudomonas*, are able to produce organic acids such as citric acid and gluconic acid, which play a role in dissolving insoluble phosphate into available forms. for plant. The bar diameter graph can be seen

in Figure 3. The graph in Figure 3 shows that the stem diameter of agarwood-producing plant seedlings increased gradually in all treatments from age 0 MST until 15 MST. Where on improvement the increase is almost the same in every observation in all treatments. The most significant increase occurred at 3 MST to 6 MST. It is suspected that the administration of PGPR in stimulating stem diameter growth is still not optimal and a longer observation period is needed to see more optimal results.

***Root weight*:** Based on analysis of variance using the F-test at the 5% significance level, the application of several PGPR concentrations significantly affected the root weight of agarwood seedlings. Analysis of variance using the F-test at the 5% significance level showed an increase in the height of agarwood-producing seedling genotypes due to the application of PGPR concentrations, indicating an interaction between genotype and PGPR concentration, indicating a significantly different effect, as shown in Table 7.

Table 7. Root Weight of Seedling Genotypes of Agarwood-Producing Plants on giving a number of concentrations PGPR age 15 MST.

Genotype	Concentration PGPR (ml/l)			
Agarwood (A)	0.00	10	20	30
A. macrocarpa	11,30 c A	12,30 b A	13,20 ab B	18,40 a A
A. malaccensis	13,50 b A	15,30 b A	23,90 a B	22,70 a A
KK = 13,12 %				

Description: Numbers followed by the same capital letter in the same row and numbers followed by the same lower case letter in the same column are not significantly different according to the DMRT test at the 5% level.

Root weight with PGPR application was heavier than without PGPR (Table 7). At PGPR concentrations of 10, 20, and 30 ml/L, there was a significant effect compared to a concentration of 0 ml/L. Giving PGPR concentrations of 10 ml/L, 20 ml/L, and 30 ml/L had the highest root weight. big that is 3.21 g compared to concentration 0 ml/L, which is 1.05 g. This indicates that the seeds given the PGPR concentration had the best effect in increasing the root weight of agarwood-producing plant seedlings. The height weight root is influential to improvement results plant production because larger roots are able to absorb water and nutrients more effectively efficient. With roots, plants can obtain the nutritional resources they need. Roots have many important functions, including supporting the plant, absorbing the nutrients in the soil needed by the plant, and assisting in applying PGPR to agarwood-producing seedlings can promote healthier, longer, and more numerous root growth compared to untreated kenaf plants, thus affecting the fresh and dry weight of kenaf roots. Improved root elongation results in increased fresh and dry weight of the roots.

Putra (2024) stated that the greater the amount of PGPR applied, the better the plant growth will be because the bacteria contained in PGPR are able to carry out their function of producing phytohormones which are useful for inducing growth, and the more optimal the dose used, the greater the effect on plant height and root length. PGPR bacteria have role as solvent phosphate (P) which is capable of speeding up absorption nutrients so that they stimulate growth root plants (Maulidan & Putra, 2024). PGPR as solvent phosphate (P) is needed plant Because There is part phosphorus in land is at in form No insoluble can absorbed by plants (Putra, 2024).

***Percentage of seedlings ready for distribution*:** Genetic quality standards are determined based on the classification of certified seed sources. Physical quality standards are determined based on the physical quality of the seedlings, which includes quantitative and/or qualitative values. During physical quality inspections, the seedlings examined must meet both general and specific requirements.

Observations of agarwood seedlings ready for distribution indicate that the application of several PGPR concentrations has the same effect on the percentage of agarwood seedlings ready for distribution. This can be seen in Table 8. Table 8 Data showing agarwood seeds the seedlings meet the criteria for ready-to-distribution. The average seedling height, stem diameter, and number of leaves exceed the agarwood seedling quality standards. This indicates that the seedlings are approximately 8 months old, calculated from before transplanting and have reached maturity. Ready channel. Besides That, giving PGPR Also give influence Which equal to all treatment so that need improved amount population PGPR which is used to optimize seedling growth. The percentage of seedlings ready for distribution is important to ensure that agarwood seedlings are well-adapted before field transfer, thereby reducing mortality risk. In general, seedling quality standards are based on morphological traits, rather than planting trials or a combination with physiological

Table 8. Percentage of seedlings ready for distribution at various concentrations PGPR at 15 months after planting.

PGPR concentration (ml/L)	Seedling height (cm)	Stem Diameter (mm)	Number of Leaves (strand)	Number of Seeds Agarwood	Percentage of Ready Seeds Channel (%)
0	30.00	4.30	14.00	20.0	100.0
10	35.00	4.44	18.00	20.0	100.0
20	41.00	4.44	22.00	20.0	100.0
30	55.00	4.70	21.00	20.0	100.0

Information: Numbers on column diameter stem Which The same different No real based on the F test at the 5% level.

characteristics. Nevertheless, such standards are useful for guaranteeing seedling quality and should be continuously refined, as they are progressive and adapt to scientific developments and best practices in the field (Syukri et al., 2014; Syukri et al., 2022; Nurmahmudi, 2024).

***Conclusion*:** Application of PGPR, particularly at 20 ml/L, significantly improved seedling growth (height, leaf traits, root weight). Both genotypes achieved 100% survival, showing strong adaptability to post-mining soils. Based on the results of the experiment, it is recommended to conduct further research. with considering PGPR concentration and population bacteria PGPR Which used. In this experiment, the administration of 2 PGPR bacteria, *Bacillus* and *Pseudomonas*, did not show an optimal effect on the growth of agarwood-producing plant seedlings in ex-coal mine planting media.

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***SDGs addressed*:** Life on Land; Climate Action; Finance and Incentivize Sustainable Forest Management.

***Policy referred*:** Regional Agricultural Development Policy; National Standards and Quality Assurance Policy; Sustainable Agricultural Practices Policy.

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